AN ADVANCED COUNTER-ROTATING DISK WING AIRCRAFT CONCEPT

Program Update

Presented to

NIAC

By Carl Grant

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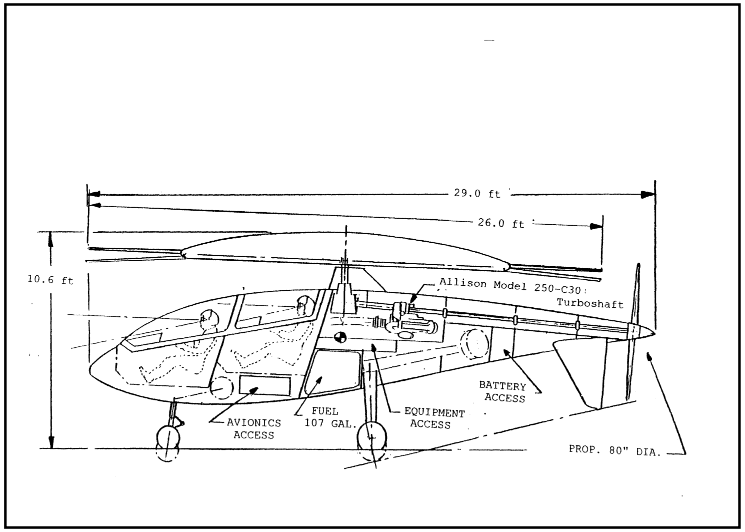
INTRODUCTION

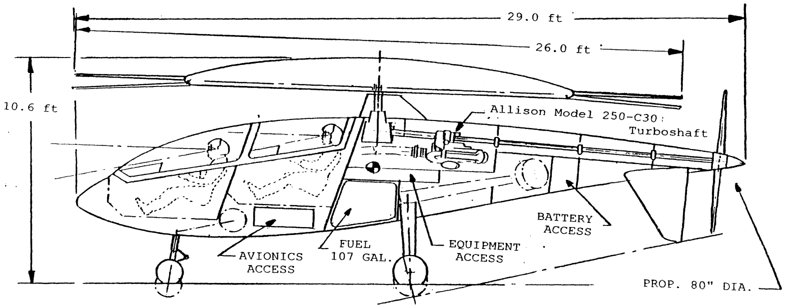
- **US Patent 4,913,376 “VTLH autogyro” filed by Franklin E. Black, April 3, 1990. Outlined basic “MODUS” concept.**
  - **disc wing for fixed wing flight**
  - **bladed counter-rotating discs for hover**
  - **gimbaled & RPM control**
- **Preliminary sizing for MODUS - XR, a high speed VTOL reconnaissance rotorcraft, performed by Vmax Technologies, for Black Technologies, 1995**
  - **Max Takeoff Weight 3300lb**
  - **available engine power is 650 shp for TKOFF, & 450 shp for CRZ.**
  - **Max SL speed 232 knots, Max @ 20K ft 150 knots**
  - **Max range, disk only, 648 nm.**
- **M85, NASA AMES design, max speed M 0.85, MGTW 10,200lb, ~400nm, 1991.**
- **Diversitech, Inc., NIAC contract, “An Advanced Counter-Rotating Disk Wing Aircraft Concept”, NIAC/USR Grant No. 07600-028, June 1st, 1999.**
  - **Max Takeoff Weight 3300lb**
  - **available engine power is 650 shp for TKOFF, & 450 shp for CRZ.**
  - **Max SL speed 300 knots, Max @ 24K ft 230 knots**
  - **Max range, disk only, 650 nm.**

Advanced High Speed Rotorcraft (AHSR) Study Objectives



- **From preliminary MODUS geometric layout define basic AHSR mission**
- **Perform a Fixed wing mission analysis using NASA Langley FLOPS program**
- **Determine Required Disk Size**
- **Determine Rotor Blade Sizing for vertical lift**
- **Perform a Hover Analysis**
- **Perform an Aeromechanical Analysis**
- **Generate Preliminary model drawings.**

From preliminary geometric layout define basic mission
(Basic Dimensions)



Disk Diameter	16ft
Rotor Diameter	26ft
Disk Area	201ft^2
Empennage Area	15ft^2
Cathedral	45^o
Taper	0.28
Thickness	12%

Frontal Area	20.54ft^2
Height	10.6ft
Length	29.4ft
Max Rotation	13^o
Propeller Diameter	80ins
Engine (Allison250-C30)	650-450 shp
MGTOW	3300lbs

From preliminary geometric layout define basic mission
(Estimated Weight Breakdown)

• **Structure**		
	- Fuselage	240 lbs.
	- Empenage	40 lbs.
	- Main Gear	120 lbs.
	- Nose Gear	30 lbs.
	- Disk	150 lbs.
	- Rotor Blades (x4)	120 lbs.
	TOTAL	700 lbs.
• **Propulsion System**		
	- Engine	280 lbs.
	- Shafts	60 lbs.
	- Clutch/G-box	100 lbs.
	- Propeller	60 lbs.
	- Actuators	50 lbs.
	TOTAL	750 lbs.

• **Systems**		
	- Electrical	190 lbs.
	- Battery	40 lbs.
	- Seats(2)	80 lbs.
	- Avionics	340 lbs.
	- FLIR	60 lbs.
	- Flight Inst.	40 lbs.
	TOTAL	750 lbs.
	TOTAL EMPTY WEIGHT	2200 lbs.
• **Crew**		
	- Pilot	200 lbs.
	- Observer	200 lbs.
• **Fuel**		
	- Internal	700 lbs.
• **Payload**		1100 lbs.
MAXIMUM TAKEOFF GROSS		3300 lbs.

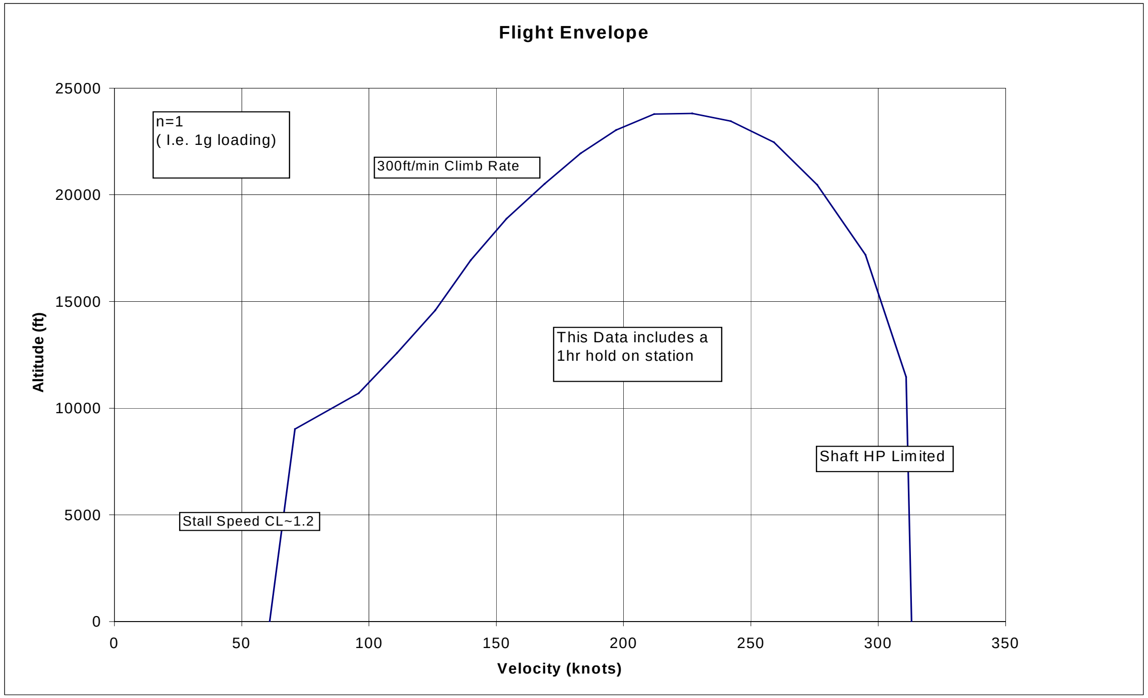
Perform a Fixed wing mission analysis using NASA Langley FLOPS program

- **The FLOPS program is a NASA Langley Flight Optimization System.**
- **Diversitech used FLOPS release 5.94, revised 17 July 1998, to perform the fixed-wing analysis.**
- **The goal of the FLOPS analysis was to verify the ability of the Vmax MODUS design to fly a set mission.**
- **The polars used for input to the FLOPS program were generated from the MODUS-XR design.**
- **Assumes a non-oxygen vehicle, i.e. not pressurized with max altitude of 12,500ft**
- **The pusher, turbo prop design, cycle was generated from a Hartzell 80”, 5 blade, propeller design, and was generated using the NASA Navy Engine Program, (NNEP).**
- **For the FLOPS analysis it was assumed that there would be available 650 shp for Take off and 450 shp for cruise. Required power determined from required speed.**
- **The Clark-Y airfoil profile was assumed for the disk.**
- **Varying Disk diameters, 22’, 26’ & 30’, considered.**

The AHS Rotorcraft Nominal Mission Used with FLOPS

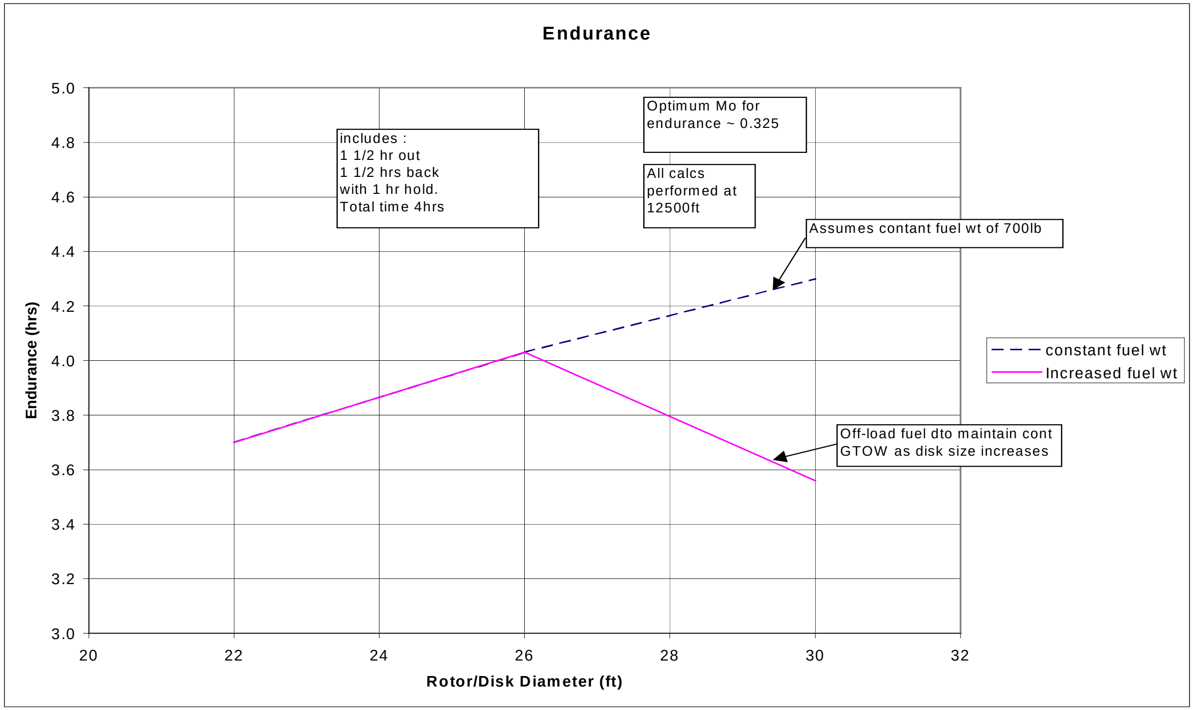
- **Max power takeoff**
- **Climb to cruise altitude of 12,500ft**
- **1½ hrs OUT**
- **descend to loiter altitude 50ft, approx.**
- **Hold on station for 1hr**
- **Climb back to cruise altitude 12,500ft**
- **1½ hrs BACK**

FLOPS Analysis Results
(Range)



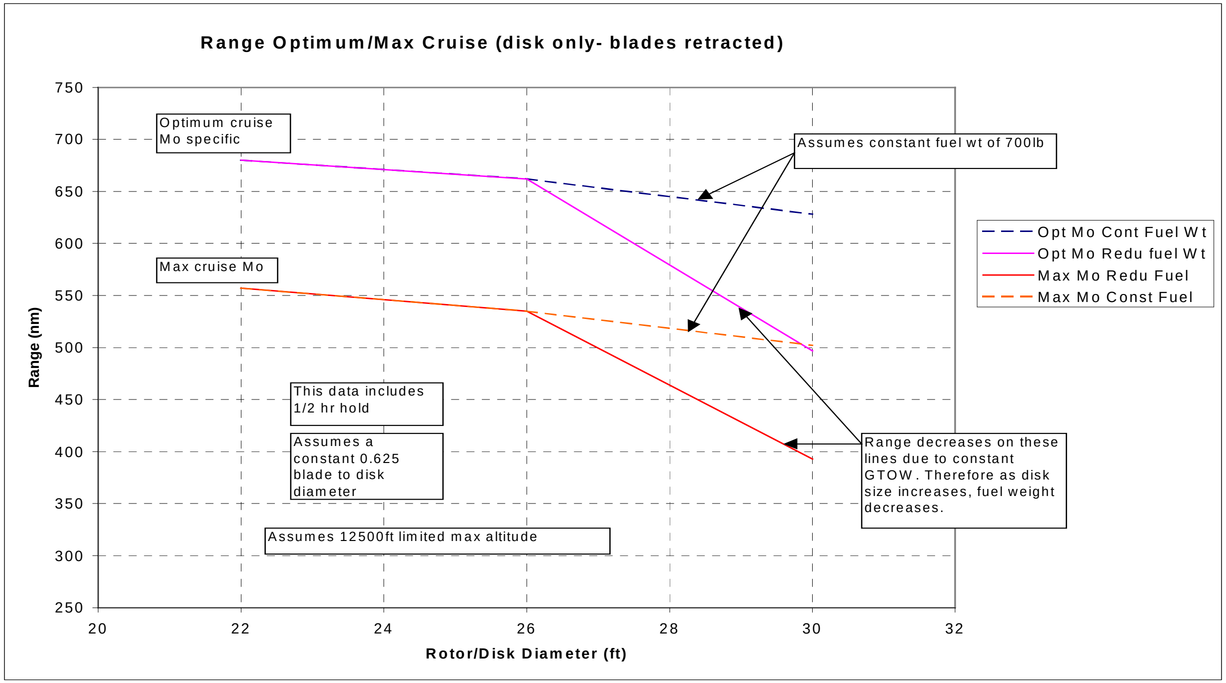
- 1g loading assumed
- Stall speed 61 knots C_L=1.16, 0ft to 900ft
- At 900ft & 70 knots to max altitude 23800ft at 227 knots, climb rate 300ft/min
- At altitude 11500ft and 311 knots to SL, Shaft HP limited

FLOPS Analysis Results
(Endurance)



- assumes 1½ hrs OUT + 1hr HOLD + 1½ hrs BACK
- Assumes constant fuel weight (dotted line)
- Assumes reduced fuel weight due to increased disk weight with GTOW constant (solid line)
- All data shown is for 12,500 ft

FLOPS Analysis Results
(Range Optimum/Max Cruise)



Optimum cruise Mo specific

Max cruise Mo

Assumes constant fuel wt of 700lb

This data includes 1/2 hr hold

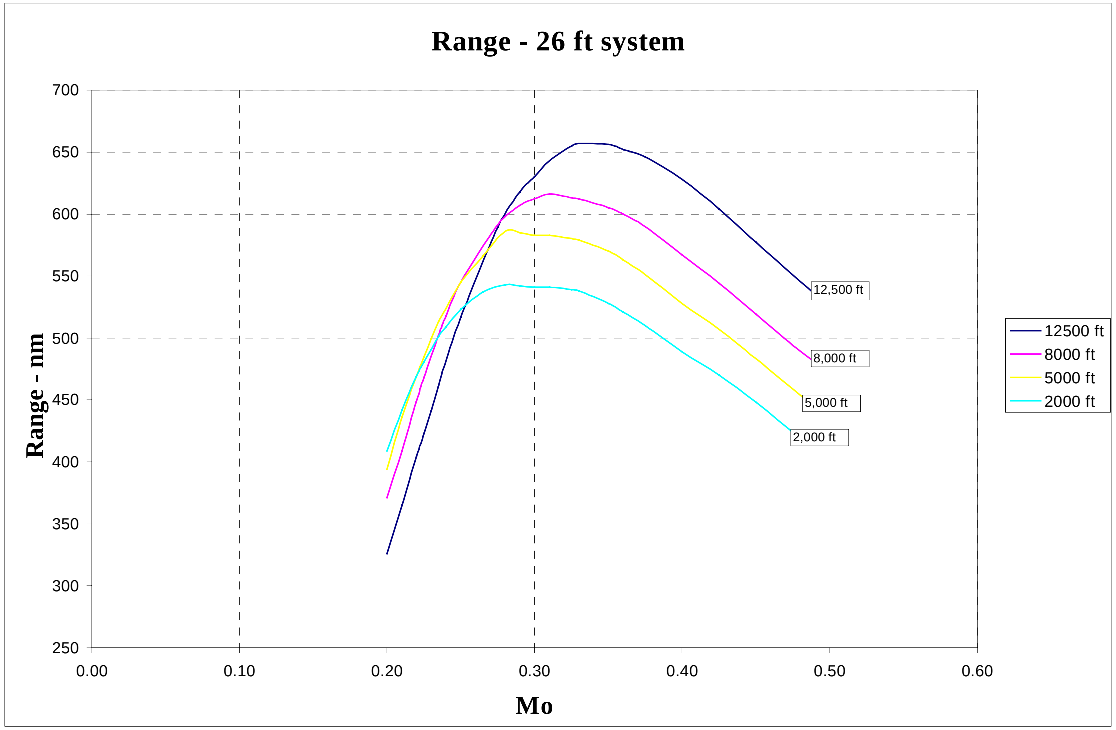
Assumes a constant 0.625 blade to disk diameter

Assumes 12500ft limited max altitude

Range decreases on these lines due to constant GTOW. Therefore as disk size increases, fuel weight decreases.

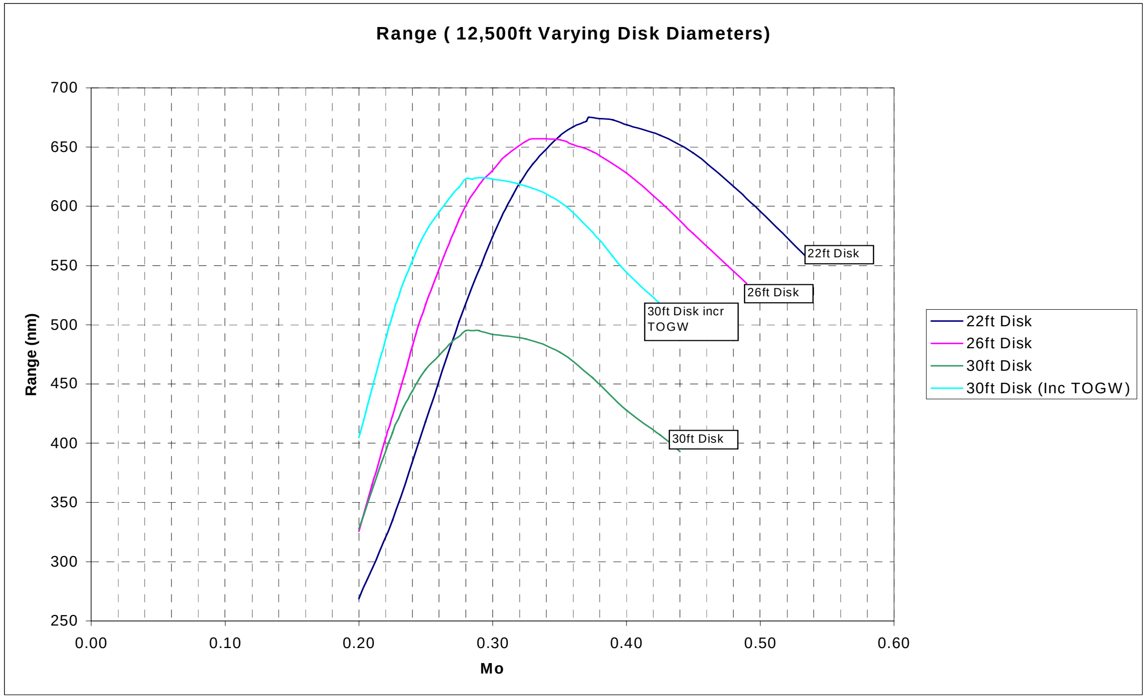
- **Assumes Disk only, blades retracted**
- **Assumes a constant 0.625 blade to disk ratio**
- **Assumes 12500ft limited max CRZ altitude**
- **Upper curves are for constant fuel weights of 700lbs**
- **Lower curves are for constant GTOW, i.e. when disk size increases, fuel weight decreases to maintain GTOW of 3300lbs**

FLOPS Analysis Results continued
(Range - 26ft Diameter Rotor)



- **Curves shown are for varying altitudes, with the upper limit being 12500ft.**
- **Assumes 16ft diameter disk with 5ft long blades**
- **Data shown is for “fixed wing” operation with blades retracted**
- **This data indicates the range decrease due to altitude**

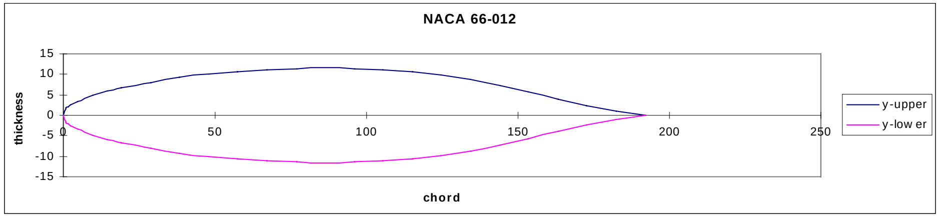
FLOPS Analysis Results continued
(Range - 12,500ft max altitude, varying disk diameters)

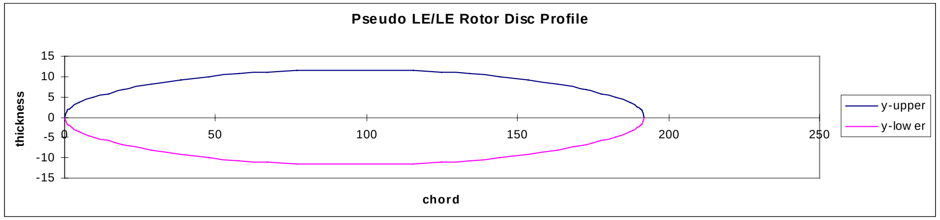


- Data shows variation in range based on changes in disk diameter.
- Assumes constant GTOW
- As disk diameter increases, fuel weight decreased to maintain 3300 lbs. GTOW
- A curve for a 30ft diameter disk, with constant fuel weight of 700 lbs., is also shown
- Note: at 12,500ft M0.5 is approximately 300 knots

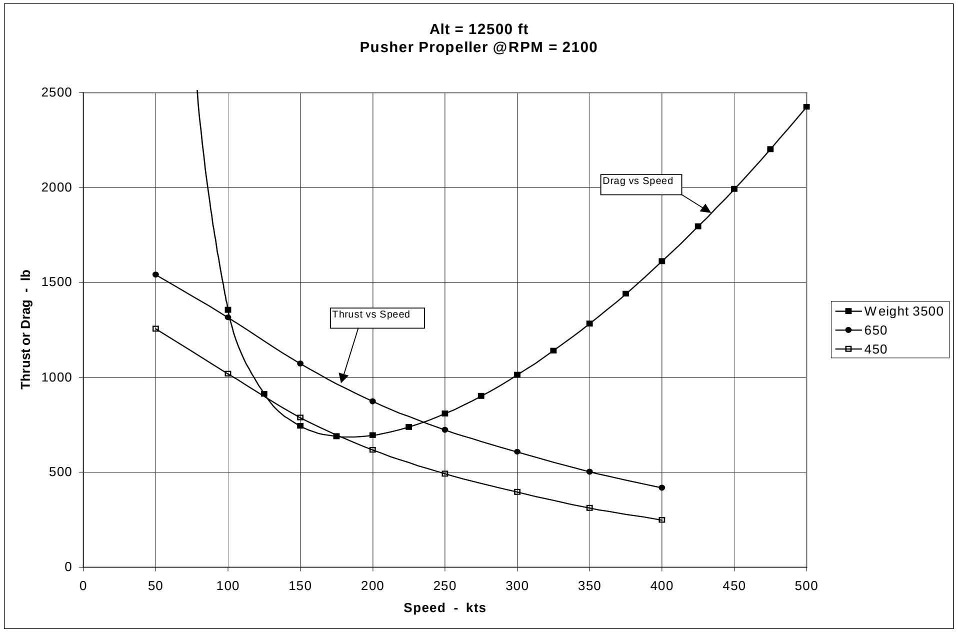
Determine Required Disk Size

- **The disk size chosen for the 3300 lbs.. GTOW vehicle is 26ft**
- **This is based on a 16ft diameter disk with 5ft rotor blades**
- **The preliminary airfoil shape chosen for the disk is a NACA 66_1-012 (chosen to provide sufficient internal volume for mechanisms)**
- **For symmetry the LE to 50% chord is used for disk profile**
- **Size chosen based on an FAA stall speed requirement, for light aircraft, of 61 knots**
- **Because of the potential for tail, or propeller, drag the landing AOA is $<15^{o}$**
- **Assume the landing weight is 2950 lbs.. (i.e. 3300lbs. minus half the fuel wt)**
- **At 61 knot stall speed data obtained from the FLOPS analysis indicates that the Clark-Y airfoil has a required $C_L \leq 1.16$, which is achievable with a 12^{o} AOA.**



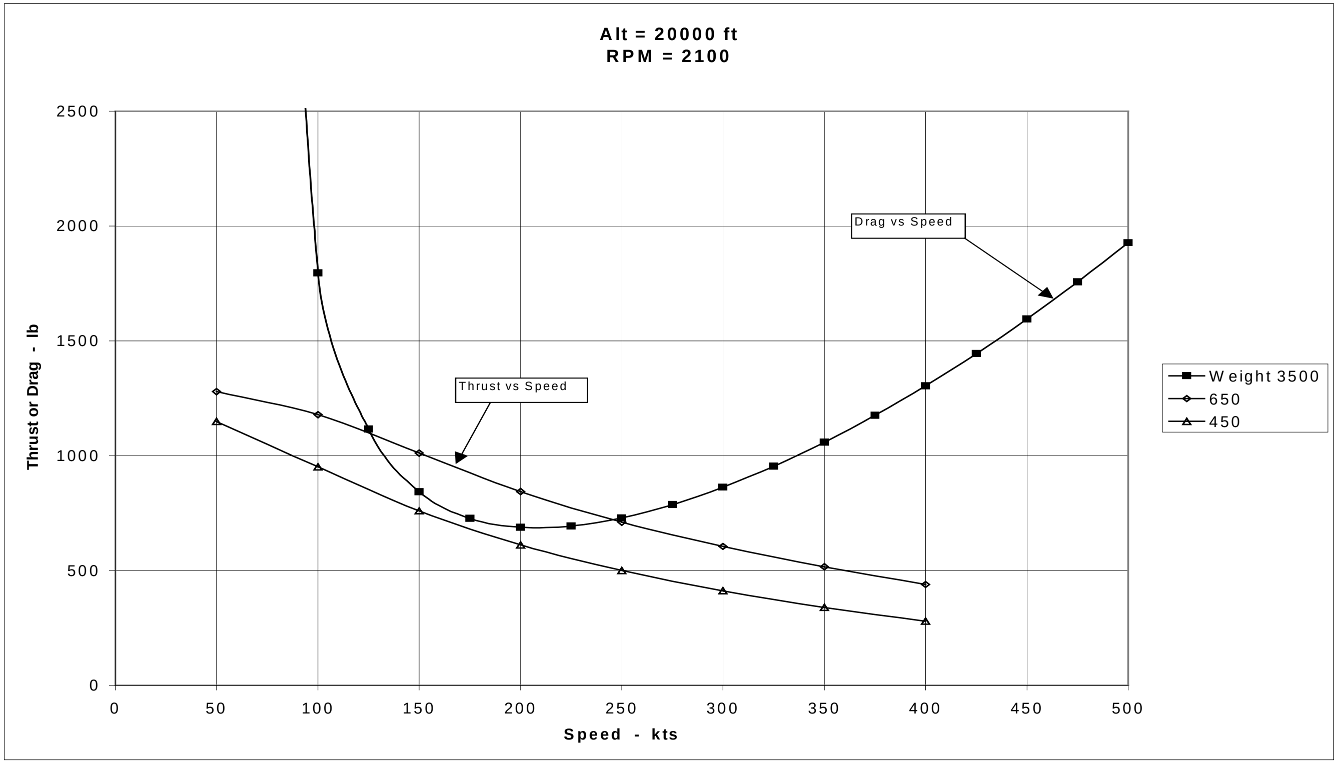


Perform Wing Lift Characteristic Analysis using US Airforce Digital DATCOM



- **Analysis performed to determine the Lift Characteristics of the pseudo NACA 66_1-012 airfoil**
- **Used NACA 66_1-012 pseudo airfoil profile, with a circular planform approximated with a polygon.**
- **Neglected gap between counter-rotating disks**
- **At 12,500ft, if 650 shp is available, the max speed is < 240 knots (determined by thrust vs drag)**
- **At 12,500ft, if 450 shp is available, the max speed is < 175 knots**
- **Need to determine correct polars for this airfoil and perform new FLOPS analysis**

Perform Wing Lift Characteristic Analysis using US Airforce Digital DATCOM



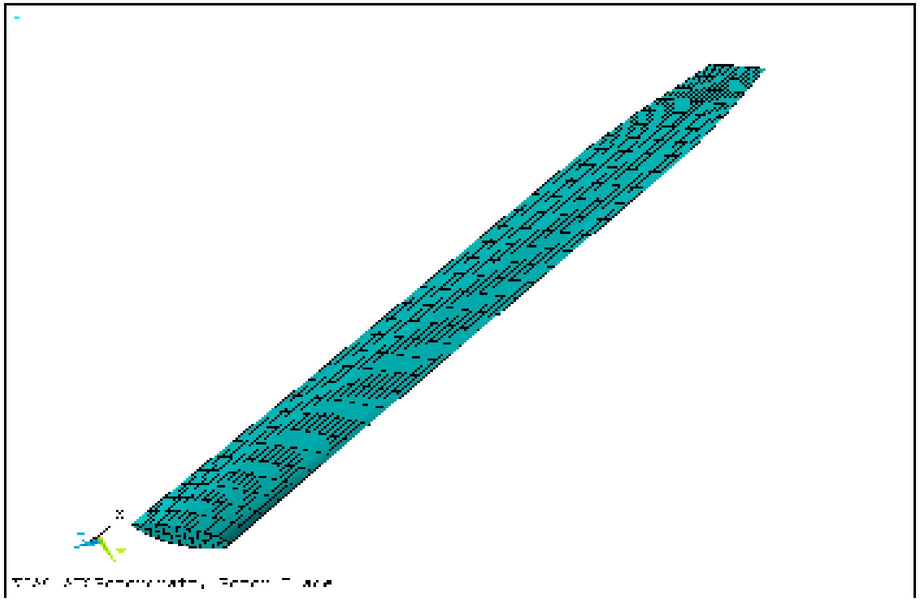
- At 20,000ft, if 650 shp is available, the max speed is < 250 knots (determined by thrust vs drag)
- At 20,000ft, if 450 shp is available, insufficient thrust is being generated by the pusher propeller to overcome the drag. Therefore, a higher horsepower would be required to overcome the drag at this altitude.

Determine Rotor Blade Sizing for vertical lift

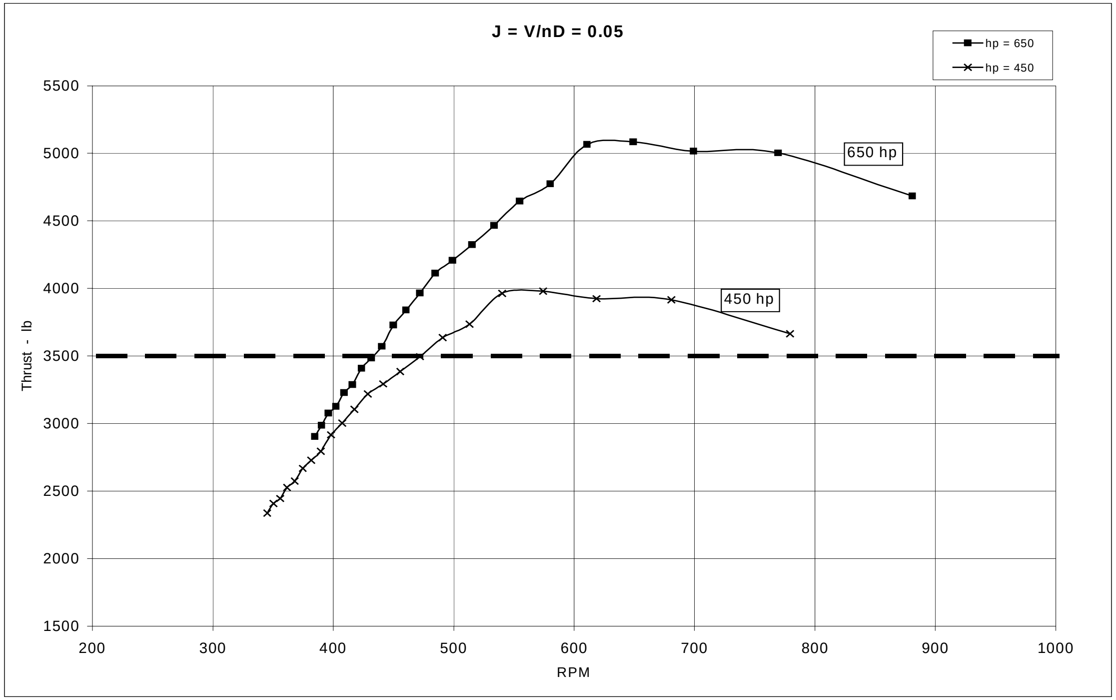
- **Rotor blade size determined for a 26ft diameter rotor, with a 16ft hub, based on the required GTOW of 3300lbs.**
- **Hartzell Propeller Company, Piqua, OH, performed the design, and provided the propeller map.**
- **Design based on 4 rotor blades with a tip diameter of 26ft.**
- **Hub diameter of 16ft included in design**
- **Available power=650 shp**
- **Design tip mach number of 0.9 used.**
- **Blade design has 60” length, and 7” chord.**

Determine Rotor Blade Sizing for vertical lift

Radius	width	thick	twist	Cl des	NACA Airfoil(chosen by Diversitech)
95	7.0	1.5	32.0	.50	16-5-21
105	7.0	1.0	30	.70	16-7-14.3
115	7.0	.70	28.5	.65	65-6.5-10
125	7.0	.55	27.5	.53	65-6.5-10
135	7.0	.40	26.7	.41	65-6.5-10
145	7.0	.30	25.8	.30	65-3-04
150	6.0	.24	25.3	.25	65-3-04
156	4.0	.20	24.9	.20	64-2-04



Perform a Hover Analysis

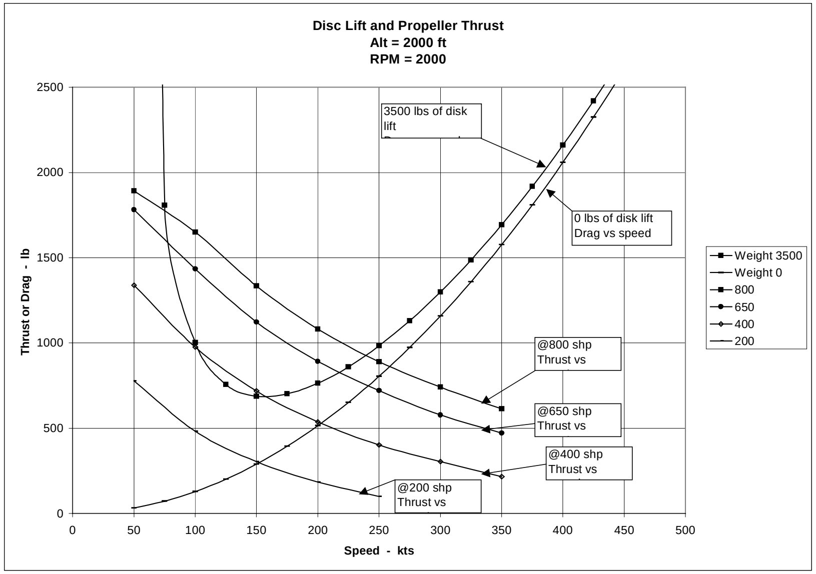


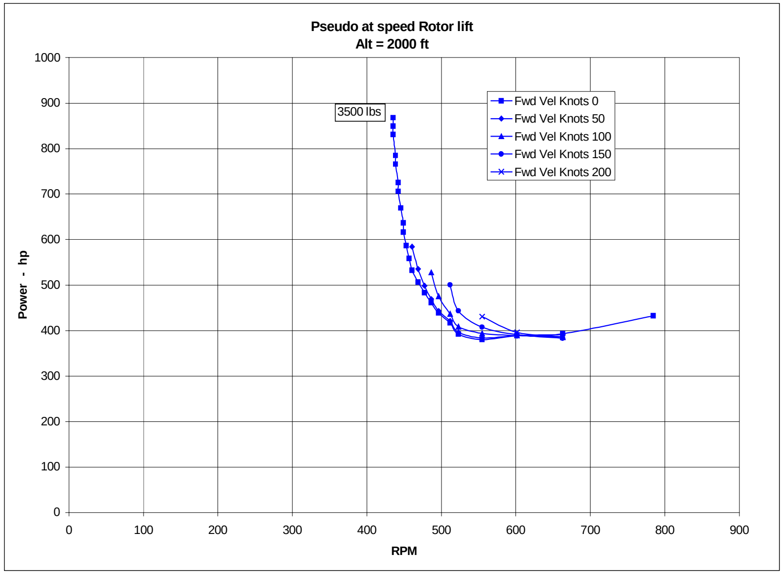
- With available 650 shp from the Allison 250-C30 engine, and the provided Hartzell rotor design, is it possible to lift 3300 lbs.. vertically?
- To provide a margin of error 3500 lbs.. lift is assumed to be required
- Analysis performed @SL with NO ground/fountain effect,
- Data shows that with 650 shp available, approx. 5000lbs of lift can be generated
- Data shows that with 450 shp available, approx. 4000lbs of lift can be generated
- The 450 shp condition allows remaining hp to be used for up&away forward flight

Pseudo Transition Analysis

- **As the rotorcraft transitions to forward flight it is assumed that the amount of lift being generated by the rotor blades will decrease.**
- **In order to transition, a constant forward velocity is chosen such that there is sufficient horsepower to**
  - **(1) drive the vehicle forward at the chosen velocity**
  - **(2) provide sufficient horsepower to rotor in order to generate 3500 lbs. of vertical lift**
- **Analysis assumes 0^o AOA for the disk**
- **Analysis does not account for blades extended drag**
- **An altitude of 2000ft is chosen, and assumed to be reasonable**

Pseudo Transition Analysis continued

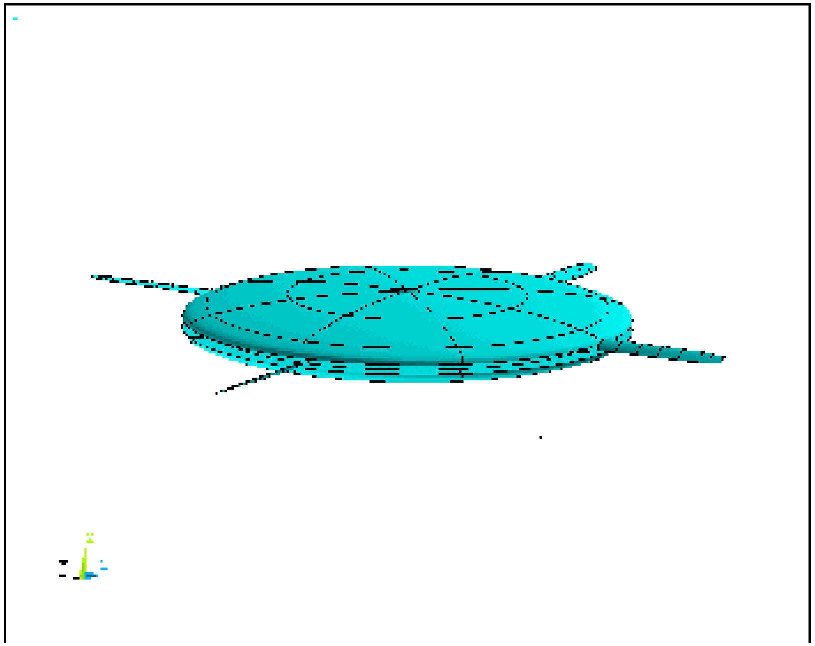




- **For 0lbs lift on disk, 200 shp is required to maintain a 150 knot forward speed**
- **At 150 knots a pseudo rotor lift of 3500 lbs. requires 400 shp**
- **There is sufficient engine power, 650 shp, to maintain this condition at 2000 ft altitude.**
- **At 150 knots, in order to generate 3500 lbs.of lift from the disk, an AOA will need to be set, and a minimum 400 shp is required.**
- **Transition is postulated to occur by transferring power from the rotor to the propeller, whilst simultaneously changing AOA on the disc.**
- **The increased disk lift will need to compensate for the reduced rotor lift due to the decreasing rotor power.**

Perform an Aeromechanical Analysis

- Preliminary Aeromechanical analysis performed by Georgia Institute of Technology, using the multi-body dynamics tool DYMORE.
- Assumes 4 bladed rotor, with the Hartzell blade design attached to the 16ft diameter NACA 66_1-012 disk.
- The analysis assumes a rigid disk boundary condition
- Work Currently in progress



Generate Preliminary model drawings.

- **Once the aeromechanical analysis is completed, assuming there are no changes required to the design, work will begin on the preliminary drawing layout of the AHSR rotor system, as determined by the results of this study.**

CONCLUSIONS

- A preliminary vehicle sizing for a 3300 lbs. GTOW Advanced High Speed Rotorcraft is nearing completion.
- The feasibility of a 3300 lbs GTOW vehicle with a 650 nm range and max speed of approx. 300 knots has been demonstrated.
- Results indicate that increased engine power may be required to meet certain mission goals such as transition. (Suggested engine is the P&W PT6A-42 engine; 850 shp, 403 lbs. weight).
- A refined FLOPS analysis that includes the NACA 66_1-012 airfoil is also suggested.
- PHASE II follow on program will encompass a CFD analysis of the disk airfoil, a refined FLOPS analysis (to include transition), along with a more detailed mechanical and aeromechanical analysis.
- For mechanical and weight purposes a single disk, with tail blowing torque control, will be studied.
- Outstanding work remaining to be completed
    - (1) complete aeromechanical analysis
    - (2) generate preliminary drawings
    - (3) write final report